COMPARISON OF RADAR AND CLEMENTINE MULTISPECTRAL REFLECTANCE DATA FOR THE LUNAR MARIA.

B.A. Campbell[1], B.R. Hawke[2], and T.W. Thompson[3], [1]Smithsonian Institution, MRC 315, Washington, DC 20560 (campbell@ceps.nasm.edu); [2]University of Hawaii, 2525 Correa Rd., Honolulu, HI 96822; [3]Jet Propulsion Lab, 4800 Oak Grove Dr., Pasadena, CA 91009.

The basalt deposits of the lunar maria vary in their composition and age, and these differences produce marked contrasts in both radar images and near-infrared reflectance data [1, 2]. These two types of observations provide complementary information. The reflectance spectrum of the lunar surface can often be interpreted in terms of bulk mineralogy, but these data respond only to the upper few microns of the regolith. Radar data cannot be directly related to composition, but do integrate the dielectric properties and rock abundance of the regolith down to a depth of perhaps 10 wavelengths. The two datasets may thus be used in conjunction to define likely surface composition and regional changes in average regolith properties. This work compares 70-cm and 7.5-m wavelength radar data to Clementine multispectral observations of the lunar nearside.

Past work has identified a number of anomalous regions within earth-based radar images, and possible reasons for changes in echo strength, including differences in rock abundance or TiO_2 content, have been proposed [3, 4, 5]. There has been little opportunity, however, to compare calibrated long-wavelength backscatter among different units or to theoretical model results. To provide a reasonable estimate of the true lunar backscatter coefficient, we combined recent high-resolution (3-5 km) 70-cm Arecibo radar data for the nearside with earlier calibrated full-disk observations [6].

The 70-cm data were then compared to models for radar scattering from a buried substrate and for Mie scattering from surface and buried rocks. These mechanisms are expected to dominate the depolarized radar echo, with their relative importance determined by the rock population, regolith depth, substrate roughness, and the loss tangent (tand) of the soil. In general, Mie scattering from buried rocks likely comprises the larger portion of the radar echo, consistent with earlier hypotheses, but returns from the underlying substrate may become important at very low loss tangents or small regolith thicknesses.

The loss tangent of the lunar regolith is dependent primarily on the proportion of lossy minerals within the soil. Previous analyses have inferred that ilmenite variations are the most likely cause of changes in 70-cm echoes across the maria, although this hypothesis has not been tested beyond the Mare Imbrium region [5]. Laboratory studies show a correlation between bulk Fe and Ti abundance and loss tangent, but the scatter in the data is very high [7]. We thus do not fully understand the role of mineralogic changes on the bulk loss tangent of the regolith.

Clementine observations of the Moon, and Apollo and Luna sample data, have been used by Lucey et al. to develop maps of lunar FeO and TiO_2 abundance [8]. The new TiO_2 values are likely more accurate at low abundances than those obtained using the Charette relationship [9], and we compared both methods to the 70-cm observations. Sample sites were chosen within each mare which encompassed the range of radar scattering behavior. Each site covers only one type of mare unit as mapped by Pieters et al. [1], and we avoided the ejecta blankets of fresh craters.

The first important result of this work is that the 70-cm depolarized radar return (a good measure of scattering by wavelength-scale rocks and absorption by the regolith) is not correlated with bulk FeO content (Fig. 1). While iron is a major constituent of ilmenite, it is also found in a variety of other minerals which do not apparently affect the microwave loss tangent. Small grains of reduced Fe in agglutinates are likewise not a major source of tand variability. The inferred correlation of loss tangent on total FeO+TiO_2 abundance from lab data may be reflective of just the ilmenite component of the samples [7].

In contrast, the 70-cm depolarized return is negatively correlated with estimated TiO_2 abundance; greater titanium content leads to lower radar echoes due to increased regolith losses (Fig. 2). The correlation between these values is best for Mare Imbrium and Oceanus Procellarum, with increasing scatter in the data for Maria Fecunditatis, Tranquilitatis, Serenitatis, and Crisium. From Figure 2, it is clear that TiO_2 changes alone do not explain the variations in 70-cm radar echo strength. Within any given mare deposit, there is a generally good fit between the two parameters, but the functional form of this dependence varies among the maria. These differences may be due to variations in overall rock abundance or regolith depth with age of the mare deposits, or to the effects of other components on the microwave loss tangent. Modulation of the loss tangent by minerals other than ilmenite is, however, considered unlikely, particularly given the lack of any relationship between radar echo and FeO content.

The 7.5-m backscatter values are poorly correlated with the 70-cm echoes. Mare Fecunditatis in particular has the lowest 70-cm return of any extensive area on the nearside, but has higher 7.5-m returns than Oceanus Procellarum and Mare Imbrium. Iron and titanium abundance appear to have little influence on the observed echo. It seems likely that the 7.5-m returns are modulated to some extent by the degree of fracturing and brecciation within the mare basalts which underlie the regolith. This is supported by the fact that older deposits tend to have higher long-wavelength echoes than do the younger Imbrian-period volcanics.

We also studied the local variability of 70-cm radar echoes within the maria and highlands. A number of impact craters, in both types of terrain, with radar-dark haloes were identified. These haloes may arise through two mechanisms: (1) by excavation of buried material which has a higher loss tangent than the material upon which it is deposited, or (2) by the emplacement of ejecta layers which have a lower rock population than the brighter surrounding regolith. In the first case, such craters may indicate the nature of the underlying mare deposits (or the presence of "cryptomare"), while the second mechanism offers significant information on the cratering process and the lifetime of such rock-poor layers. We plan to use Clementine data to discrimate between these two possibilities.

Future mapping at 12.6-cm and 70-cm wavelengths will help to resolve some of the issues raised here, but this work demonstrates that significant geologic information may be gained from the synthesis of microwave and multispectral data.

References: [1] Pieters, C., Proc. LPSC 9th, 2825-2849, 1978; [2] Thompson, T.W., J.B. Pollack, M.J. Campbell, and B.T. O'Leary, Radio Science, 5, 253-262, 1970; [3] Thompson, T.W., Icarus, 36, 174-188, 1978; [4] Pollack, J.B., and L. Whitehill, J. Geophys. Res., 77, 4289-4303, 1972; [5] Schaber, G.G., T.W. Thompson, and S.H. Zisk, The Moon, 13, 395-423, 1975; [6] Hagfors, T., Radio Science, 5, 189-227, 1970; [7] Carrier, W.D., G.R. Olhoeft, and W. Mendell, in Lunar Sourcebook, Cambridge Press, New York, 1991; [8] Lucey, P.G., G.J. Taylor, and E, Malaret, Science, 268, 1150-1153, 1995; [9] Johnson, J.R., S.M. Larson, and R.B. Singer, J. Geophys. Res., 96, 18,861-18,882, 1991.